FY23 Topic Areas Research and Technology Development (TRTD)

Laboratory Electrical Conductivity Measurements for Exploring Ocean Worlds

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Strategic Focus Area: Solar System characteristics and origin of life

Objectives:

Geophysical measurements can reveal the interior properties of icy ocean worlds. Such measurements can point to the presence and temporal variability of fluids and gases, thus identifying potential habitable niches for life. The thickness and geodynamics of different ice phases, and the depth of the ocean, determine the conditions under which life might exist. The global fluxes of chemical energy must be understood in terms of a world's interior structure and evolution. Such a global picture is necessary for quantifying the types of life and amounts of biomass that might be supported. Interpreting the results from magnetic induction measurements assumes good knowledge of the electrical conductivity of the solutions, but available electrical conductivity data do not cover the range of possible conditions. Available data generally extend to a maximum concentration of 30 parts per thousand (ppt), with no consideration for the effects of high pressure. Coverage at temperatures other than 25°C is less reliable. Salinities of ocean worlds can extend well beyond 30ppt, and pressures in the largest oceans can reach 1GPa (10,000 bar).

Background:

Europa Clipper's investigation of habitability requires geophysical measurements to reveal the depth, thickness, and salinity of Europa's subsurface ocean. These properties are fundamental to understanding Europa's evolution and redox state, and thus to the kinds of life it might support. Europa Clipper has a Level 1 science requirement to "**Constrain our knowledge of the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to ±50%.**" Europa Clipper Magnetometer (ECM) measurements will constrain the electrical conductivity structure $\sigma(r)$ of the interior of Europa. However, currently, the lack of measurements of candidate ocean fluids at high pressures and low temperatures (HPLT; pressures >20MPa and temperatures <0 ◦C) will prevent an accurate determination of the ocean salinity. Moreover, interpreting Europa Clipper's suite of geophysical measurements (radar, magnetic, gravity) calls for self-consistent models that account for the thermodynamic and transport properties of its materials. Addressing this dearth has applications to the other large moons of Jupiter, and to the icy moons of Saturn, Uranus, and Neptune.

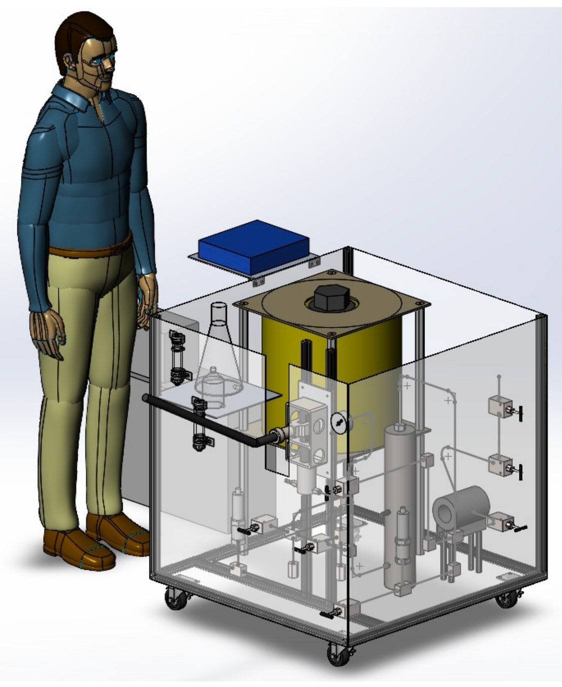
Approach and Results:

We developed the newly commissioned JPL Simulator for Icy World Interiors (SIWI) apparatus to measure electrical conductivity up to 700 MPa from -20 to 20 °C for the solubility ranges of NaCl and MgSO4. In FY23, we have continued to refine the system, addressing the robustness of the wiring, adding wire guides and shielding to address inductive effects observed during testing. Meanwhile we have implemented the software and hardware needed for pressure and temperature readout and control.

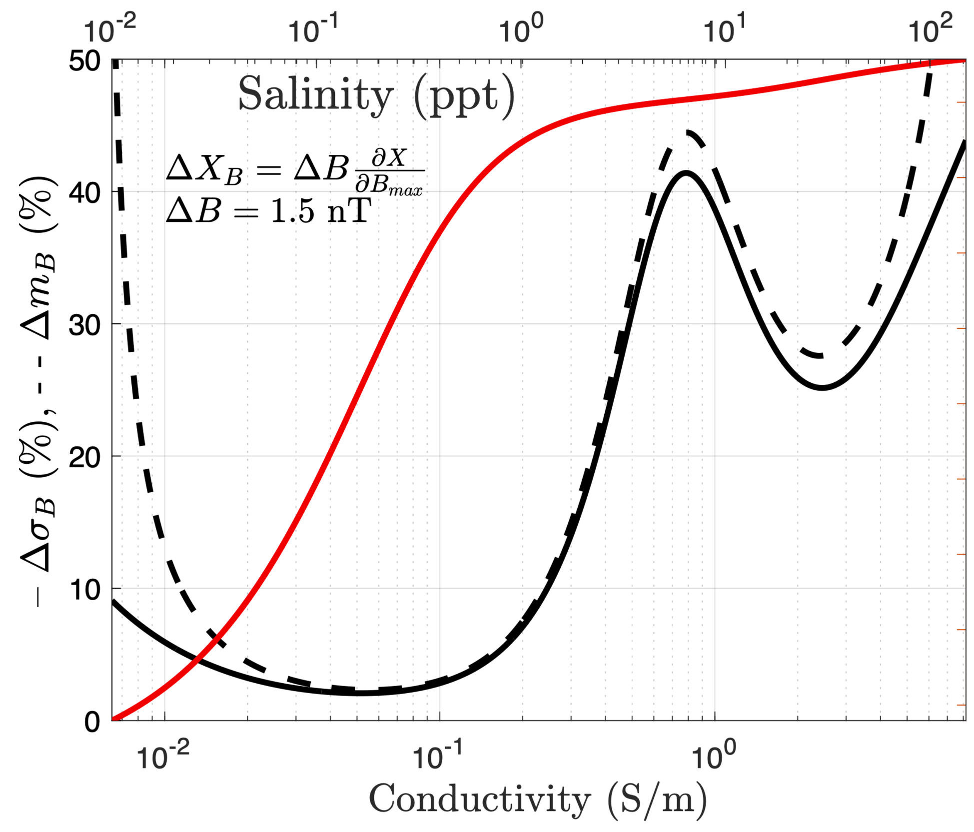
We identified the needed precision of measurements to be better than 1% for salinity in the range 0.1 wt%. Available measurements at 1 atmosphere have repeatability in this range, but do not extend to temperatures below 5°C. Measurements at high pressure and high salinity (1-10 wt%) have uncertainties in the range 10-15% at best; 10% uncertainty may be adequate in this range. Galileo magnetic constraints on Europa's ocean salinity are consistent with values in the broad range considered here. We conducted preliminary measurements in sodium chloride solutions and NIST-traceable standard KCl solutions at 1 atmosphere. The use of NIST standards and cross calibration will be essential to achieving the desired accuracy.
Simultaneously, we continued molecular dynamics (MD) simulations to predict the conductivity behaviors of NaCl solutions. Such an approach was used in recently published work by Pan et al. (2021). Our analyses demonstrate that MD simulations do not provide the needed precision and representations of water's behavior appear to better match conductivity trends in different regimes of pressure and temperature. The completed work for NaCl demonstrates that MD simulations will provide useful insights into the trends of our measurements, but current MD capabilities cannot provide the needed sensitivity to better than 1%.
We made significant progress toward establishing a verified approach to obtaining the measurements needed to interpret magnetic induction measurements by Europa Clipper, JUICE, and future ice giants missions. The timing of this progress was opportune, with the releases of the ROSES funding opportunity, Preparatory Science Investigations for Europa (Step 2 due date of December 16, 2022). Our modeling approach gave us a distinct advantage when proposing because we demonstrated the application of our laboratory data to simulated magnetic induction measurements in highly realistic models of ocean worlds. PSIE selected 5 of the 28 proposals received. Ours was one of those selected.

Significance/Benefits to JPL and NASA:

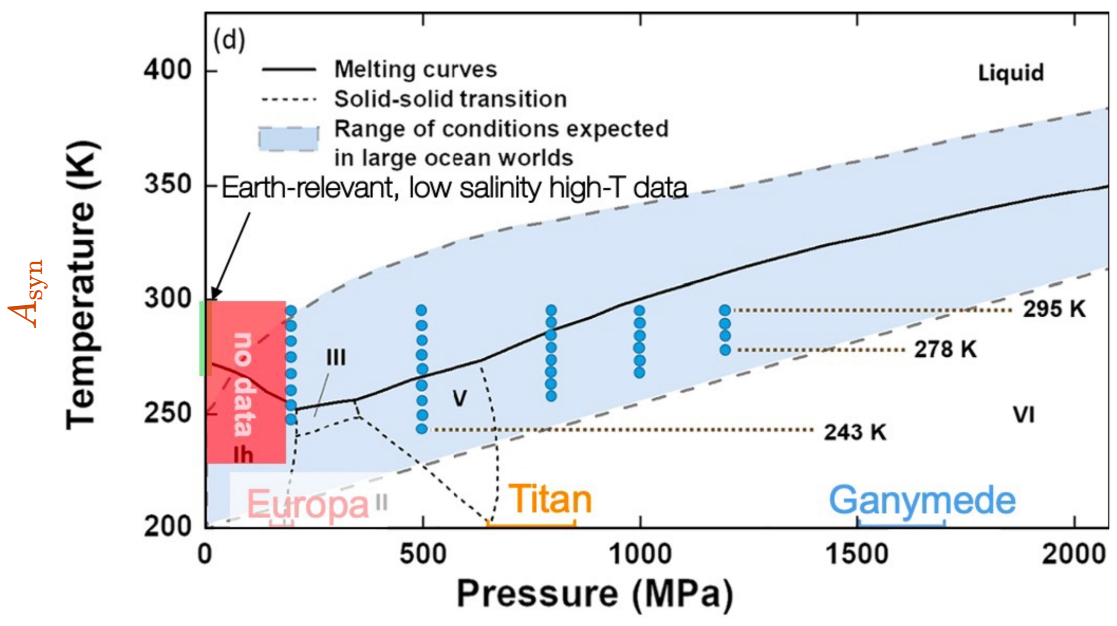
The NASA funding, lab development, and modeling work supported by this RTD have positioned us to provide essential laboratory electrical conductivity data needed to support the Europa Clipper L1 of inferring the ocean's salinity. The NASA funded work supports an integrated team that will combine additional thermodynamic data and modeling expertise to provide for the joint inversion of magnetic sounding and gravity science data. This integrated approach constitutes the state of the art being pursued by other groups and is likely to be an essential part of future ocean worlds missions.



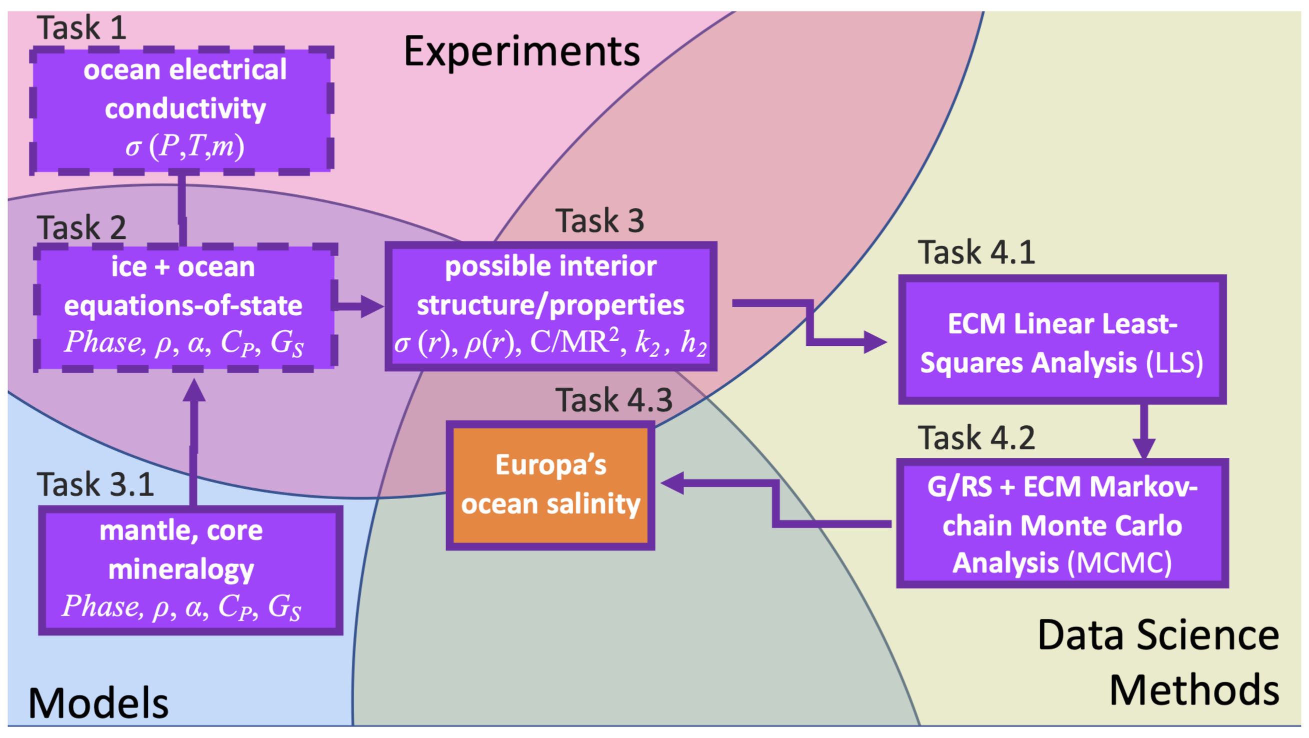
The setup for measuring properties of ocean world solutions is being reformulated to be more ergonomic



***Black:** noise-equivalent sensitivity of conductivity σ, salinity m referenced to 1.5 nT noise in the magnetic induction measurement.*
***Red:** Induction amplitude for Europa's synodic response.*



Electrical conductivity data are missing at pressures relevant to Europa (red rectangle). A handful of measurements were recently published at higher pressure conditions relevant to Titan and Ganymede, but only at very high salinity conditions where the low sensitivity (>15% uncertainty) was warranted. Modified from Pan et al. 2021.



Plan of work for awarded NASA Precursor Science Investigations for Europa (Clipper), "Joint Inversion of Magnetic Induction and Gravity Science Measurements Using New Laboratory Data for Europa Analog Solutions.

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Clearance Number: CL#00-0000
Poster Number: RPC#

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